The analysis of spinopelvic parameters and stability following long fusions with S1, S2 or iliac fixation

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Abstract

Purpose The purpose of this study was to analyse changes of spinopelvic parameters and stability in the treatment of degenerative lumbar deformity.

Methods A retrospective review was carried out on 70 cases of degenerative lumbar deformity treated by long fusion with uni-cortical S1 fixation alone (US1F group, $n=20$), bi-cortical S1 fixation alone (BS1F group, $n=20$), additional diagonal S2 fixation (DS2F group, $n=14$), and additional iliac fixation (ILF group, $n=16$) from July 2003 to April 2010. The sagittal vertical axis (SVA), lumbar lordosis (LL), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), and stability were used to evaluate radiologic outcomes. The

clinical outcome was evaluated using the Oswestry Disability Index (ODI).

Results In all groups, the LL was significantly increased at three months ($p<0.05$). The PI and the SS of ILF patients significantly increased at three months ($p<0.05$), while none of these values changed over time in non-ILF patients. The PT did not change postoperatively in any groups. The LL, SS, and PI were significantly greater in the ILF group at three months postoperatively and later ($p<0.05$). DS2F and ILF had statistically significant stability compared to US1F and BS1F ($p<0.05$). The ODI scores were significantly improved after surgery in all groups compared to before surgery ($p<0.05$).

Conclusions Patients who had ILF in long fusion for the treatment of degenerative lumbar deformity had significant restoration of spinopelvic parameters compared to the other groups. In addition, DS2F and ILF provided more stability of distal instruments.

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Introduction

The pelvis and spine can be regarded in the sagittal plane as a linear chain linking the head to the legs. So, spinopelvic imbalance in degenerative lumbar deformity can lead to functional impairment and disability and can cause accelerated degenerative disc and joint disease [1]. Several studies have shown that adequate restoration of sagittal plane alignment is necessary to significantly improve clinical outcomes and avoid subsequent pseudarthrosis [2–4]; however, these studies have focused on clinical outcomes or identification of radiographic findings that might predict curve or symptom progression [5–8], and it is still necessary to study the values of and relationships among all of the parameters of spinopelvic balance after surgery.

A single S1 screw fixation is often not sufficient to obtain adequate power when fusing the lumbosacral junction due to

heavy loads and weak bone characteristics often seen in the sacrum. In an attempt to address these problems, various instrumentation and operative techniques have been developed. Nonetheless, many issues including metal failure, pseudarthrosis, and halo signs are still reported [9, 10].

The aim of this study was to compare and analyse (1) all of the parameters of spinopelvic balance and (2) the stability of distal instruments among long fusions in patients with degenerative lumbar deformity.

Materials and methods

The patients with degenerative lumbar deformity who underwent posterolateral fusion of more than four segments including sacrum fixation with pedicle screw fixation from

July 2003 to April 2010 were retrospectively assessed, and 70 cases that allowed for more than two years of follow-up were included in the study.

The mean age was 66.0 years (range, 56–81), with nine males (16 %) and 49 females (84 %). The mean period of follow-up was 67.1 months (24–115) and the mean fusion level was 5.1 segments (four to nine).

All of the patients had severe low back pain for at least 12 months, sciatica, and/or neurogenic claudication. The indications for surgery were symptomatic degenerative lumbar deformity and spinal stenosis as confirmed by plain radiography and supplementary magnetic resonance imaging. All of the patients had failed to respond to conservative therapies. None of the patients had a history of previous spinal surgery involving decompression and/or fusion.

The patients were divided into four groups. There were 20 patients who underwent fixation of the S1 screws in a single cortical bone plane (uni-cortical fixation, US1F group), 20

Fig. 1 The sagittal vertical axis (SVA) was defined as the distance from the perpendicular line drawn at the center of C7 in the sagittal plane to the posterior superior end plate of S1. The angle of lumbar lordosis (LL) was measured from the inferior endplate of T12 to the superior endplate of S1

Fig. 2 The sacral slope (SS) is the angle between the superior sacral endplate and a horizontal reference line. The pelvic tilt (PT) is the angle between the line connecting the midpoint of the superior sacral plate to the center axis of the femoral heads and a vertical reference line. The pelvic incidence (PI) is the angle subtended by a line drawn from the center of the femoral heads to the midpoint of the sacral endplate and a line perpendicular to the center of the sacral endplate (S1)

who underwent fixation in both cortical bone planes (bi-cortical fixation, BS1F group), 14 with additional diagonal S2 screws along with S1 fixation (DS2F group), and 16 who received additional iliac screws (ILF).

Radiologic measurement

Whole-spine standing lateral radiographs were taken with standard 37-inch film preoperatively and three months and 24 months postoperatively. The hip joints and cervical spine were also included. The patients were instructed to stand straight and relaxed with knees fully extended. Three researchers (Y.S.P., S.W.B., and K.Y.H.) measured all parameters twice with a one-month interval.

In terms of spinal parameters, sagittal decompensation was defined by sagittal vertical axis (SVA) >50 mm based on the standing lateral radiography [11]. The degree of lumbar lordosis (LL) was assessed by Cobb's method from the inferior end plate of T12 to the superior endplate of S1 [12] (Fig. 1). As pelvic parameters, the sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI) were measured by the method of Beaupere et al. [13] (Fig. 2).

The degrees of correction loss in the sagittal planes as well as the presence of instability of the distal instruments were compared according to the results of standing radiography

between three months and 24 months postoperatively. For the measurement of instability of the distal instruments, lumbosacral fracture, metal breakage, pull-out, and halo sign around the screws were assessed randomly on two occasions, one month apart.

Clinical measurements

The Oswestry Disability Index (ODI) was used before and two years after surgery to compare low back and leg pain before and after surgery [14]. ODI data were documented for ten scales: pain intensity, personal care, lifting, walking, sitting, standing, sleeping, sex life, social life, and traveling.

Statistical analysis

The data were analysed using the SPSS 20.0 software (SPSS, Inc., Chicago, IL). Statistical analysis was performed. *P* values for independent variables were generated using the Wilcoxon test, the Kruskal-Wallis test and the Fisher's exact test. When the *p*-value was less than 0.05, the analysis was evaluated to be significant.

The inter- and intra-observer agreement was calculated with intraclass correlation coefficient (ICC) model for the

Table 1 Comparison of radiographic measurements for the spinopelvic parameters

Measurement	US1F	BS1F	DS2F	ILF	<i>p</i> value
SVA (cm)					
Pre-op	3.2±3.1	6.2±4.0	8.5±3.9	8.6±4.4	0.001*
Three-months PO	3.3±1.9	4.3±3.1	3.0±3.1	3.3±4.1	0.827
Two-years PO	6.5±3.1	7.5±3.4	6.6±5.3	5.6±2.5	0.369
LL (°)					
Pre-op	19.8±10.7	18.7±11.2	19.8±10.9	18.7±11.0	0.933
Three-months PO	26.1±4.7	26.2±5.2	26.0±3.1	30.3±1.5	0.026*
Two-years PO	25.1±5.3	26.0±4.1	26.1±4.2	29.6±3.3	0.023*
SS (°)					
Pre-op	26.4±6.5	27.0±7.9	25.4±4.7	24.3±3.0	0.603
Three-months PO	27.0±1.6	27.1±1.4	27.3±2.8	29.6±2.7	0.017*
Two-years PO	27.1±1.3	27.2±1.9	27.1±1.8	29.4±2.9	0.007*
PI (°)					
Pre-op	51.6±3.0	53.4±3.5	52.7±4.1	52.9±3.4	0.509
Three-months PO	52.8±3.2	53.5±4.0	54.1±2.7	56.8±2.5	0.004*
Two-years PO	53.8±4.4	53.2±3.2	53.3±2.2	56.3±2.5	0.028*
PT (°)					
Pre-op	25.3±7.1	26.4±6.1	27.3±8.0	28.6±4.8	0.437
Three-months PO	25.8±3.1	26.4±3.9	26.8±4.4	27.1±3.8	0.692
Two-years PO	26.7±4.1	26.0±3.3	26.1±3.1	26.9±3.6	0.742

US1F uni-cortical fixation group, BS1F bi-cortical fixation group, DS2F diagonal S2 screws along with S1 fixation group, ILF iliac screw fixation group, PO postoperative, SVA sagittal vertical axis, LL lumbar lordosis, SS sacral slope, PT pelvic tilt, PI pelvic incidence

*Significantly greater than the value found in other groups (*p*<0.05)

angles and distances of the parameters, and the kappa statistics for the instability.

Results

There was no statistically significant difference in age, gender, bone density, and levels to be fused before the operation among the four groups ($p>0.05$).

In the pre-operative spinopelvic parameters, the SVA was significantly greater in ILF and DS2F patients than in the other groups ($p=0.001$), while the other preoperative parameters showed no significant differences among the four groups (Table 1).

Regarding the spinal parameters, SVA was significantly decreased at three months postoperatively in all but the US1F group, but increased later. The LL in all groups significantly increased at three months postoperatively and did not change later. The SVA of BS1F (6.2 ± 4.0), DS2F (8.5 ± 3.9), and ILF groups (8.6 ± 4.4) decreased to 4.3 ± 3.1 ($p=0.044$), 3.0 ± 3.1 ($p=0.016$), and 3.3 ± 4.1 ($p=0.005$), respectively, at three months postoperatively, but increased to 7.5 ± 3.4 ($p=0.001$), 6.6 ± 5.3 ($p=0.014$), and 5.6 ± 2.5 ($p=0.019$), respectively, at

24-months postoperatively. The LL after US1F (19.8 ± 10.7), BS1F (18.7 ± 11.2), DS2F (19.8 ± 10.9), and ILF (18.7 ± 11.0) was significantly increased to 26.1 ± 4.7 ($p=0.026$), 26.2 ± 5.2 ($p=0.020$), 26.0 ± 3.1 ($p=0.046$), and 30.3 ± 1.5 ($p=0.007$), respectively, at three months postoperatively (Table 2).

The DS2F patients had the lowest SVA values at three-months postoperatively (3.0 ± 3.1), while the later SVA values were lowest for ILF patients (5.6 ± 2.5), although this was not a statistically significant difference ($p>0.05$). LL was significantly greater in the ILF group at three months postoperatively (30.3 ± 1.5) ($p=0.026$) and later (29.6 ± 3.3) ($p=0.023$) (Table 1).

Regarding the pelvic parameters, in ILF patients all but the PT significantly increased at three months postoperatively, but did not change later. The PI (52.9 ± 3.4) was significantly increased to 56.8 ± 2.5 ($p=0.001$) and the SS (24.3 ± 3.0) was significantly increased to 29.6 ± 2.7 ($p=0.002$) at three-months postoperatively in ILF patients. However, in non-ILF groups, none of the pelvic parameters changed over time (Table 2).

The SS values were significantly greater in ILF patients at three months postoperatively (29.6 ± 2.7) ($p=0.017$) and later (29.4 ± 2.9) ($p=0.007$). The PI was significantly greater in the

Table 2 Pre-operative measurement and postoperative change in the spinopelvic parameters

Groups	Pre-op	Three-months PO	p value	Two-years PO	p value
SVA (cm)					
US1F	3.2 ± 3.1	3.3 ± 1.9	0.850	6.5 ± 3.1	0.000 ^a
BS1F	6.2 ± 4.0	4.3 ± 3.1	0.044 ^a	7.5 ± 3.4	0.001 ^a
DS2F	8.5 ± 3.9	3.0 ± 3.1	0.016 ^a	6.6 ± 5.3	0.014 ^a
ILF	8.6 ± 4.4	3.3 ± 4.1	0.005+	5.6 ± 2.5	0.019 ^a
LL (°)					
US1F	19.8 ± 10.7	26.1 ± 4.7	0.026 ^a	25.1 ± 5.3	0.351
BS1F	18.7 ± 11.2	26.2 ± 5.2	0.020 ^a	26.0 ± 4.1	0.889
DS2F	19.8 ± 10.9	26.0 ± 3.1	0.046 ^a	26.1 ± 4.2	0.969
ILF	18.7 ± 11.0	30.3 ± 1.5	0.007 ^a	29.6 ± 3.3	0.378
SS (°)					
US1F	26.4 ± 6.5	27.0 ± 1.6	0.932	27.1 ± 1.3	0.849
BS1F	27.0 ± 7.9	27.1 ± 1.4	0.932	27.2 ± 1.9	0.857
DS2F	25.4 ± 4.7	27.3 ± 2.8	0.166	27.1 ± 1.8	0.747
ILF	24.3 ± 3.0	29.6 ± 2.7	0.002 ^a	29.4 ± 2.9	0.937
PI (°)					
US1F	51.6 ± 3.0	52.8 ± 3.2	0.253	53.8 ± 4.4	0.449
BS1F	53.4 ± 3.5	53.5 ± 4.0	0.925	53.2 ± 3.2	0.751
DS2F	52.7 ± 4.1	54.1 ± 2.7	0.408	53.3 ± 2.2	0.301
ILF	52.9 ± 3.4	56.8 ± 2.5	0.001 ^a	56.3 ± 2.5	0.063
PT (°)					
US1F	25.3 ± 7.1	25.8 ± 3.1	0.831	26.7 ± 4.1	0.543
BS1F	26.4 ± 6.1	26.4 ± 3.9	0.955	26.0 ± 3.3	0.699
DS2F	27.3 ± 8.0	26.8 ± 4.4	0.529	26.1 ± 3.1	0.561
ILF	28.6 ± 4.8	27.1 ± 3.8	0.134	26.9 ± 3.6	0.448

US1F uni-cortical fixation group, BS1F bi-cortical fixation group, DS2F diagonal S2 screws along with S1 fixation group, ILF iliac screw fixation group, PO postoperative, SVA sagittal vertical axis, LL lumbar lordosis, SS sacral slope, PT pelvic tilt, PI pelvic incidence

^a Significantly changed from the value of previous time-point ($p<0.05$)

Table 3 Comparison of correction loss in the sagittal planes

Measure	US1F	BS1F	DS2F	ILF	p value
Loss of sagittal balance (cm)	3.2±2.7	3.1±2.6	3.4±4.5	3.0±3.0	0.673

US1F uni-cortical fixation group, *BS1F* bi-cortical fixation group, *DS2F* diagonal S2 screws along with S1 fixation group, *ILF* iliac screw fixation group

ILF group at three months postoperatively (56.8 ± 2.5) ($p=0.004$) and later (56.3 ± 2.5) ($p=0.028$). The ILF showed the largest PT at three months postoperatively (27.1 ± 3.8) and later (26.9 ± 3.6). However, there was no statistically significant difference ($p>0.05$) (Table 1).

As for the sagittal balance, there was an average correction loss of 3.2 ± 2.7 in US1F patients. In the BS1F group, the correction loss was 3.1 ± 2.6 on average. In DS2F, the correction loss was 3.4 ± 4.5 on average, while the ILF patients showed average correction loss of 3.0 ± 3.0 . ILF showed the least correction loss; however, there was no statistically significant difference ($p=0.673$) (Table 3). All parameters were measured with good reproducibility (interobserver mean ICC, 0.923 [0.876–0.996]; intra-observer mean ICC, 0.967 [0.889–1.000]).

Instability of the distal instrument was detected in a total of 17 cases (23 %), including seven cases (35.0 %) in the

US1F group, six (30.0 %) in the BS1F group, two (15.3 %) in the DS2F group, and two (12.5 %) in the ILF group. The US1F and BS1F patients showed significantly higher rates of instability as compared with DS2F and ILF patients ($p=0.046$), but there was no statistically significant difference between the US1F and BS1F patients ($p=0.947$) or between the DS2F and ILF patients ($p=1.00$). Kappa coefficients for inter-observer agreement for subgroup were 0.950, 0.967, and 0.910, indicating almost perfect agreement. Intra-observer agreement was also almost perfect, with kappa coefficient values of 0.934, 0.918, and 0.951.

Of the three patients that received S1 pedicle screw treatment and had instability of distal instruments, there was one case with DS2F and one case with ILF, and a revision was provided. A revision was suggested for the remaining patient, but it was declined. Thus, they were being monitored through follow-up.

Fig. 3 A 74-year-old female patient was admitted due to back pain, bilateral sciatica, and neurogenic claudication. Preoperative radiographs showed narrowing of multiple lumbar disc spaces, severe

spondylosis and degenerative scoliosis (*left*). Postoperative radiographs showed decompressive laminectomy and posterior-lateral fusion of L2–S1 with diagonal S2 screws (*right*)

The ODI improved significantly after surgery in all four groups ($p < 0.05$). In the scores for social life and travel in the ODI at the final follow-up, the patients of the DS2F and ILF groups showed statistically significant and higher clinical satisfaction compared to other groups, reporting average scores of 1.69 (1–3) and 1.53 (1–4) for the former and average scores of 1.76 (1–3) and 1.53 (1–3) for the latter ($p = 0.006, 0.018$) (Figs. 3 and 4).

Discussion

Failure of the patient's compensatory mechanisms for spinal balance in degenerative lumbar deformity may require a surgical solution, and there has also been an emphasis on achieving spinal balance in the sagittal plane as well, and in addition to the coronal plane, in deformity correction.

In previous studies, many authors have reported that the PI played a predominant role in determining the shape of the sagittal curvature [13, 15–17]. This role of PI in determining the sagittal curvatures is through significant correlations between PI and SS and between SS and LL. Therefore, we analysed all spinopelvic parameters after long fusions among

patients with degenerative lumbar deformity, and observed that a well-balanced position with regards to the long fusion was obtained not only through SVA and LL, but also by optimizing pelvic parameters (PI, PT, and SS).

In this study, the pre-operative LL, SS, and PI were not significantly different among the groups, but in ILF patients, LL, SS, and PI were significantly increased at three months postoperatively, and these values were significantly greater compared with other groups at three months postoperatively and later. Significantly increased LL, SS and PI values in ILF patients might indicate that iliac fixation with long fusion is more powerful to maintain the sacral orientation compared to fusion without iliac fixation, so that ILF was thought to be effective in restoration of sagittal plane alignment of the spine and pelvis. Conversely, the pre-operative SVA was significantly greater in ILF and DS2F. This means that the iliac fixation and the diagonal S2 fixation was primarily performed for degenerative lumbar deformity patients with severe sagittal decompensation in this study.

Meanwhile, the PI is a constant value only if the orientation between the sacrum and the pelvis is maintained [18]. In other words, the PI may be changed only if the spatial correlation between the sacrum and the pelvis is changed

Fig. 4 A 64-year-old male patient was admitted due to back pain, bilateral sciatica and neurogenic claudication. Preoperative radiographs showed narrowing of multiple lumbar disc spaces, severe spondylosis

and degenerative scoliosis (*left*). Postoperative radiographs showing decompressive laminectomy and posterolateral fusion from T12-S1 with iliac screws (*right*)

during a lifetime. This correlation is probably determined by the articulation of the sacroiliac joint. Some studies support one instance where the PI can change individually: PI values increase with aging [19], and they have generally been found to be greater in patients with adult spinal deformity than in normal individuals [20]. In the present study, the PI value in ILF patients significantly increased following surgery and the high values were maintained for up to two years postoperatively. Increased PI after ILF might be explained by the changes in the sacroiliac joint articulation following the operation. Therefore, the current results suggest that the PI is not a constant value, but a variable affected by long spinal fusion with iliac fixation.

Biomechanically, since the sacrum has low bone mineral density and considerable load is introduced, the power of S1 pedicle screw fixation is relatively less than that of the lumbar spine. For this reason, many techniques have been introduced and applied to protect the S1 screw and increase the fixation power of the distal instruments. Between these methods, the iliac screw is presently the most general technique used, and it is known biomechanically to have a strong fixation power [21, 22]. However, Kim et al. [23] compared S2 screws and iliac screws mechanically in a cadaver study and found that the S2 screw could be replaced with the iliac screw, as there was no significant difference between the fixation power of the screws over compression, flexion, extension, lateral bending, and rotation load.

In this study, the instability of the distal instruments was statistically significant in US1F and BS1F patients, and it helped to secure the stability of the distal instrument with additional DS2F or ILF when performing a long fusion among patients with degenerative lumbar deformity. However, there was no statistically significant difference when comparing DS2F and ILF, thus, DS2F is thought to secure the stability of the distal instruments while reducing issues such as extensive muscle damage that can be generated with ILF, as well as skin irritation caused by the instruments, and difficulty of securing fixation power when conducting posterior iliac bone harvest.

This study had several limitations. First, it failed to describe related risk factors of the instability by comparing the clinical and radiological characteristics in the patients that maintained stability and those who developed instability. However, we designed the review so that there was no statistically significant difference in the age, gender, bone density, and levels to be fused in the four groups in order to ensure comparability. Second, we could not determine the correlation between the values of PI and sacroiliac joint degeneration, or whether clinical effects of a postoperatively changed PI on sacroiliac joint in fusions with iliac fixation were favourable to the patients. However, we did observe that ILF with long fusion had more power to control sacral orientation compared to fusion without iliac fixation. Third,

the results were derived through follow-up for a relatively short period of time from among a relatively small number of patients who allowed a minimum follow-up period of at least two years. Therefore, it is still necessary to conduct periodic observations to monitor for the loss of correction, which can be generated during long-term follow-up. Evaluation for instability of the distal instruments should also continue over a long-term follow-up period. Moreover, there is a need to conduct further analysis in a greater number of cases.

In conclusion, when performing a long fusion for lumbar degenerative deformity DS2F and ILF were found to be effective to secure the stability of distal instruments and restore spinopelvic balance. However, in cases of severe osteoporosis, degenerative lumbar scoliosis demanding long fusion and revision surgery, ILF might be effective to restore sagittal plane alignment of the spine and pelvis.

More importantly, understanding patterns of variation in the spinopelvic parameters along with the relative stability provided by the various distal instruments can lead to more effective treatment paradigms for degenerative lumbar deformity.

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